The UlTra® System: A High Resolution Tracking System for Unexploded Ordnance Surveys

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ABSTRACT

Magnetic and radiometric environmental surveys for unexploded ordnance and radiation contamination are improved by collecting high resolution, position-correlated survey data. These data fully document the survey's results, and permit computer modeling and analysis to identify minimal targets and characteristics.

Differential global positioning system (DGPS) tracking is a convenient method for determining location in open areas, but it is inaccurate in wooded areas or around structures due to the attenuation and reflection (multipathing) of the satellite signals. DGPS is also expensive for the high resolution/accuracy required for locating small targets.

This paper describes the UlTra® (Ultrasonic Tracking) System, a new, low cost, local positioning system employing ultrasonic time-of-flight technology. This System has high resolution and accuracy, and is suitable for use in most terrains, including wooded areas or even inside of buildings. The System is operated manually to determine individual locations, or automatically to continuously track the surveyor at the rate of once per second. The current speed of sound and wind effects are automatically measured at each location. The UlTra System is lightweight and easily moved from area to area. Its short ultrasonic pulse (25 kHz) does not disturb the surveyor nor animals in the area.

BACKGROUND

UXO surveys conducted by walking over the area while swinging a metal locator or magnetometer, then placing a marker where the audible output from the sensor directs, leave considerable uncertainty regarding the reliability of the survey's results. Documentation of such a survey typically consists of only field notes and hand drawings. This is of questionable sufficiency for such high danger potential as UXO, particularly in the case of areas that are being transferred to public or commercial use under the Base Closure and Realignment Act (BRAC) program.

Fig. 1 Reference Station; Rover (insert left); Transmitter Pod (insert right)

Tracking technologies have been developed for automatically tracking the surveyor and simultaneously recording the sensor's output in a digital memory. These data are used to provide track maps which document precisely the manner in which the area was covered by the surveyor, and to produce color coded maps showing in detail the sensor's output over the area.

The USRADS® System, developed by the Oak Ridge National Laboratory in the mid-1980's, demonstrated the utility of using ultrasonic time-of-flight as a tracking technique for walkover environmental surveys. Of particular importance for the purposes of UXO surveying is the ability of the USRADS System to track the surveyor in the wooded areas that are common on UXO ranges. However, the commercial version of the USRADS System is expensive, with the price of the complete system approaching $100,000. It is also complex to use in field operations requiring a team of experienced operators.

Laser tracking has been evaluated, but it is difficult to use in wooded environments due to the time for the tracking mechanism to reacquire the surveyor's location following the loss of the signal due to tree shadowing. Reacquisition times of several seconds are not uncommon in such environments.

INSTRUMENTATION DEVELOPMENT

System description. The UlTra System consists of the three components shown in Fig. 1.

Rover. This small unit, about the size and weight of a TV remote control, contains a radiofrequency (RF) transmitter/receiver (transceiver), a single ultrasonic transmitter (25 kHz), a connector for attaching the Transmitter Pod, and two serial I/O ports. It is powered by a standard 9V alkaline battery. The Rover can be hand carried, or otherwise attached to the surveyor. A block diagram of the Rover is shown in Fig. 2.

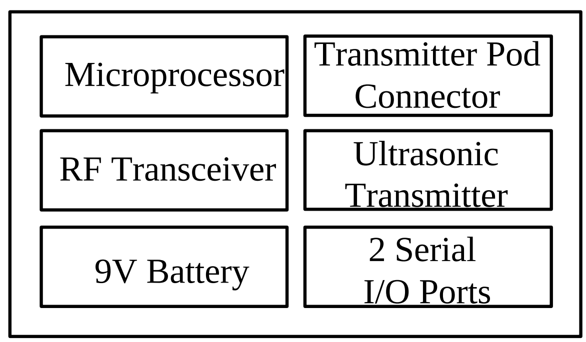

Fig. 2 Block diagram of Rover

Reference Station. The Reference Station has receiver pods at the end of each of four arms extending from a center box. Each pod has six piezoelectric receivers which are resonant at the same frequency as the ultrasonic transmitters in the Rover and the Transmitter Pod. The ultrasonic detection and timing circuitry is in the pods. The center box is mounted on a tripod and contains the RF transceiver. An ultrasonic transmitter mounted in the center of the top of the box provides data for continuous updates for the speed of sound and wind effects. The Reference Station is powered by two external, sealed 12V lead acid batteries mounted on the tripod legs, or alternately by two internal 9V alkaline batteries. The block diagram for the Reference Station is shown in Fig. 3.

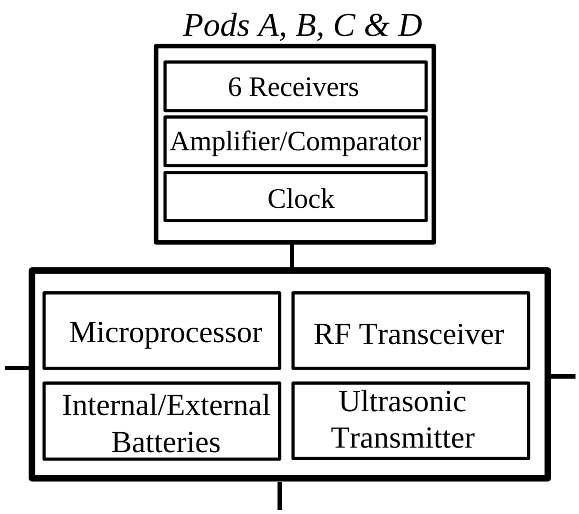

Fig. 3 Block diagram of Reference Station

Transmitter Pod. The Transmitter Pod, which plugs into the Rover, is mounted on a survey instrument to provide 360 transmission of the ultrasonic signal. This lightweight unit is particularly useful for field surveying where it is inconvenient to always point the Rover toward the Reference Station. Tracking accuracy is also improved by mounting the Transmitter Pod directly over the survey instrument's sensor. The Rover's ultrasonic transmitter is automatically disabled when the Transmitter Pod is plugged in.

Theory of Operation. To measure a location, the Rover's ultrasonic transmitter, or the Transmitter Pod, emits a short pulse, and simultaneously transmits a low power RF pulse. The Reference Station starts a timing clock for each receiver pod immediately upon receipt of the RF signal. As each receiver pod detects the arrival of the ultrasonic signal, its clock is stopped. Note that since only the leading edge of the ultrasonic pulse is used to stop the clock, sound reflected from some other object and hence traveling a longer distance, will not affect the measurement.

Following the detection of the ultrasonic signal by the Reference Station receivers, a second ultrasonic pulse is emitted by a transmitter located at the center of the Reference Station's arms. The transmission times of this pulse over the known lengths of the arms are used to measure the current speed of sound and the wind velocity.

The times-of-flight of the Rover/Transmitter Pod's ultrasonic signal to each of the receivers are then used along with the speed of sound and the wind velocity to calculate the location of the Rover/Transmitter Pod.

Reference Station Design. There were two principal reasons for choosing four receivers in an orthogonal array of equal arm lengths.

Shallow angle avoidance and position averaging. Slight errors in the timing measurements become large errors in determining the Rover's location anytime the Rover is nearly colinear with the two receivers used in the calculation. This is sometimes referred to as the shallow angle problem, and is illustrated in Fig. 4a.

Such errors cause the distance circles drawn around the two receivers to either not intersect, or else intersect at a location quite remote from the correct location. For this reason, it is preferable for the Rover's location to be as close as possible to the normal bisector to the line between the receivers.

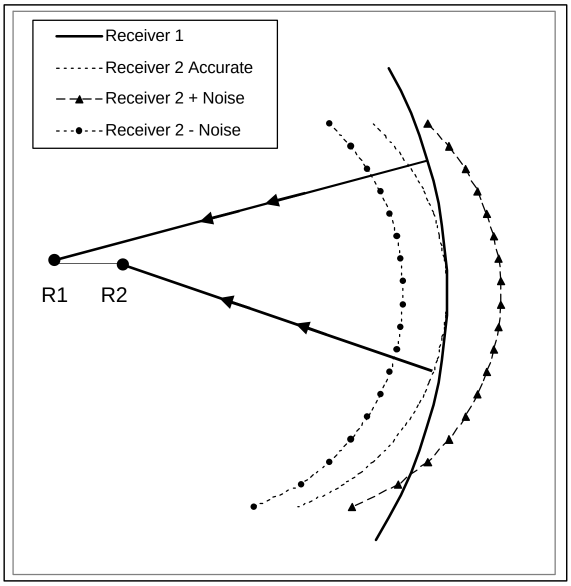

Fig. 4a. Shallow angle problem

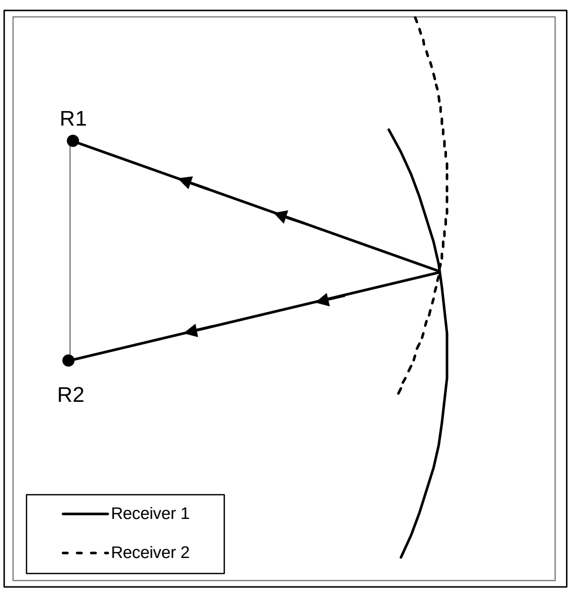

Fig. 4b. Optimum Receiver Orientation

With the UlTra System design, it is always possible to choose three pairs of receivers such that the angle between the Rover's location and the normal bisector to the line joining each receiver pair is less than 45 degrees. This is illustrated in Fig.5. A simple comparison of the timing values to the four receivers permits the octant of the Rover's location to be determined, and the three preferred receiver pairs are selected accordingly.

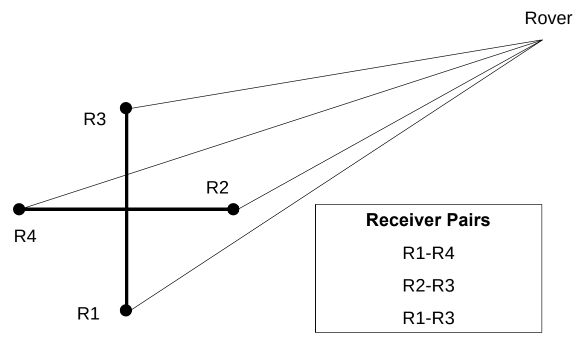

Fig. 5. Selected receiver pairs

The system is furthermore made less sensitive to timing measurement errors by averaging the locations calculated from the three selected receiver pairs.

2. Measuring the speed of sound and compensating for wind effects. The travel times of this pulse from the ultrasonic emitter in the center of the array along the fixed arm lengths measures the current speed of sound. Thus, there is no need for a special procedure to periodically measure this parameter as it changes during the day with changes in temperature and barometric pressure.

The travel times along the arms can also be used to calculate transmission time changes along each axis caused by the wind. While wind effects will vary somewhat between the location of the Reference Station and the Rover, the distance is sufficiently short to make such a correction beneficial in a strong breeze.

The Technology. The selection of the ultrasonic and radiofrequency transmitters/receivers was critical to the successful development of the system.

a. Ultrasonic transmitters/receivers. Industrial grade, 16 mm diameter, piezoelectric transmitters and receivers are used due to their narrow bandwidth, small size, ruggedness and low cost. The sensitivity of these receivers is reduced by 20 dB within 2 kHz from their 25 kHz resonant frequency, making them highly immune to extraneous environmental noise. A timing resolution of 4 µsec is achieved through high gain amplification and the summing of the signals from the six receivers in each pod. This corresponds to a distance of approximately 0.1 cm at the typical speed of sound.

b. RF transceivers. Single chip RF transmitters and receivers are used for easy design integration and to minimize cost. No external components are required for these chips other than the antenna. A RF switch is incorporated so that a single antenna can be used for both transmission and reception. A communication range of over 300 feet is provided by these units using standard quarter wavelength, whip antennas.

A significant requirement is that the radiofrequency system be capable of reliably transmitting 50 bytes of information from the Reference Station to the Rover each second. The data are Manchester coded, i.e. coded so that the same number of 1's and 0's were transmitted, to improve the transmission reliability.

System Output. The System outputs eight, five digit numbers at the end of each location measurement. These are the four times-of-flight of the Rover's/Transmitter Pod's ultrasonic signal to each of the receiver pods, plus the four times-of-flight of the speed of sound signal from the transmitter on the Reference Station box to the four receivers. These data are output in ASCII format at 9600 baud from the Rover's Serial Port #1.

The Rover's Serial Port #2 is provided for interfacing to the survey instrument. Several interfacing strategies are possible depending on the output of the survey instrument and the preference of the user. Some survey instruments contain sufficient memory so that the UlTra System's data can be stored in this memory along with the survey instrument's data, as with the Geometrics G-858 Portable Cesium Magnetometer/Gradiometer. In other cases, it is preferable to transmit the survey instrument's data to the Rover through Serial Port #2, and then out through Serial Port #1 along with the UlTra System's data to a portable memory device such as a palmtop computer.

A simple DOS program is provided with the UlTra System for post-processing of the output timing data into coordinates.

PERFORMANCE

The stability of the UlTra System's output is determined by placing the Rover at a stationary separation from the Reference Station and measuring the standard deviation of the variation of the output coordinates from their mean values. At 3 m separation, the standard deviation is 0.1 cm, and at 25 m separation it is 10 cm.

The useful range of the UlTra System is demonstrated by walking away from the Reference Station while carrying the Rover. Fig. 6 shows the results of this experiment. Note that the walk was made without any guideline, so some of the slow variation from a straight line is due to walker drift. The system is shown to be sufficiently accurate for field environmental surveys out to a range of approximately 25 m, especially if the survey is conducted in a fixed pattern so that spurious output coordinate values can be easily identified and deleted. This is the half-diagonal for a 35 m x 35 m survey area (~0.25 acre).

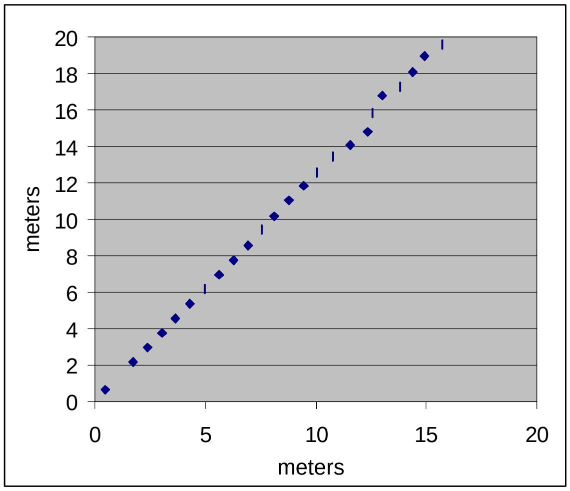

Fig. 6 Range test

FUTURE DEVELOPMENTS

Investigations remain to determine the maximum power that can be put into the ultrasonic pulse so as to extend the range of the UlTra System. Since only a short pulse is required, the piezoelectric transducers appear to be capable of transmitting a large amount of power without damage.

A three dimensional capability is planned by adding a fifth receiver pod on a vertical arm extending above the Reference Station box.

Where Co. anticipates integrating various survey instruments, the UlTra System, and inexpensive color palmtop computers into a highly effective field instrumentation package. This would enable the surveyor to review a color track map of the survey results at any time during the survey.